Chapter 3
Prospective Secondary Mathematics Teacher Preparation and Technology

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1 Introduction

Practitioners and researchers interested in prospective secondary mathematics teacher (PSMT) preparation can see technology as both an object of PSMT learning and a means for that learning. In this chapter, we present a systematic review of empirical literature to describe how PSMTs benefit from technology use in teacher preparation.

To arrive at the set of references, the first author searched each of nine core mathematics education journals for articles published between 2000 and 2015 using key words: "technology", "pre-service" or "prospective", and "secondary mathematics teachers". Abstracts, theoretical backgrounds and methodology sections indicated 25 articles that reported empirical results. A search of six refereed journals focused on technology, mathematics education, or teacher education[1] for articles published between 2000 and 2015 using "secondary mathematics teachers" and either "pre-service" or "prospective" as key words. Upon careful reading the 35 articles, we selected 18 that focused on prospective secondary mathematics teachers and reported an empirical study.

[1]International Journal for Technology in Mathematics Education, International Journal of Mathematical Education in Science and Technology, Journal of Technology and Teacher Education, Contemporary Issues in Technology and Teacher Education, Journal of Research on Technology in Education, Journal of Digital Learning in Teacher Education.

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We observed that the articles could be sorted into three categories based on contexts of PSMT preparation in which the empirical work occurred: (1) mathematics content courses; (2) methods or pedagogy courses; and (3) teaching practicum. Within each venue, we note trends and questions regarding the PMSTs' experiences with technology. All reviewed articles addressed, either explicitly or implicitly, knowledge about content, pedagogy, technology, or interactions or combinations thereof.

2 Framing Knowledge and Course Redesign

Knowledge about content, pedagogy, technology, and combinations of these areas might be framed by Technological, Pedagogical and Content Knowledge (TPACK). TPACK refers to the knowledge on which teachers rely for teaching content with appropriate digital technologies (Koehler and Mishra 2008; Mishra and Koehler 2006). Built upon Shulman's (1986) ideas, the structure of knowledge associated with TPACK includes three major components of knowledge: content knowledge, pedagogical knowledge and technological knowledge. The model "emphasizes the complex interplay of these three bodies of knowledge" (Koehler and Mishra 2008, p. 1025) with Shulman's pedagogical content knowledge (PCK) and the introduction of technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK).

Niess (2012) argued that those preparing teachers for meeting the challenges and demands for teaching mathematics with appropriate 21st century digital technologies must address the question of how pre-service teachers' preparation programs should be re-designed to describe appropriate learning trajectories for learning to teach mathematics in the 21st century. A redesigned course or practicum should engage pre-service teachers with rich pedagogical, technological, and content problems, maintaining the complexity of the interrelationships among these bodies of knowledge. Within the following discussion of content courses, pedagogy courses, and practicum, redesign of experiences provides the context and motivation of several empirical works.

3 Content Courses and Technologies

Four articles examined whether various technologies could be used to promote PSMTs' understanding of mathematics content (Cory and Carofal 2011), increase their performance in mathematics content (Kopran 2015; Zengin and Tatar 2015), or change their attitudes toward using technology in teaching and learning mathematics (Halat 2009; Kopran 2015; Zengin and Tatar 2015).

Findings from three of the studies (Cory and Carolal 2009; Halat 2009; Zengin and Tatar 2015) suggest PSMTs' use of dynamic environment or interactive technology might help them develop a better understanding of the content. These results arose across mathematics content, including limits of sequences (Cory and Carolal 2009), polar coordinates (Zengin and Tatar 2015), and statistics (Kopran 2015). Researchers employing qualitative methods (Cory and Carolal 2009; Zengin and Tatar 2015) explored conceptual understanding while work using quantitative methods (Kopran 2015) focused on comparisons of performance. Use of such constructs as concept image (Tall and Vinner 1981) might be helpful in articulating how the technology use contributed to richer content knowledge.

Three studies indicated that use of dynamic software (Halat 2009; Zengin and Tatar 2015) or interactive, web-based learning tool and resources (Kopran 2015) could develop participants' positive attitudes toward teaching and learning mathematics with technologies. For example, PSMTs involved in Koparan's (2015) study showed positive attitude toward learning statistics, perhaps identifying the technology as interesting and useful tools for data processing. Halat (2011) examined the effects of PSMTs designing a Webquest, a computer-based learning and teaching model in which learners are actively involved in an activity or situation and use the Internet as a resource. His participants' attitudes and perceptions changed as they noted the usefulness of Webquest for motiving students and assessing students' learning, and promoting students' collaboration.

4 Pedagogy or Methods Courses and Technologies

Thirteen articles examined how to develop PSMTs' understanding through pedagogy or methods courses. Each of the studies addressed technology in combination with one or both of content and pedagogy.

Only one of the 13 articles addresses pedagogy. Zembat (2008) examined the nature of mathematical reasoning and algebraic thinking in a paper-and-pencil environment compared to that in a technology-supported environment (Sketchpad and Graphing calculators). He used Sternberg's (1999) model to describe three types of reasoning:

> Analytical reasoning refers to the ability to think about formulas and applications of those to abstract mathematical problems that usually have single correct answers. … Practical reasoning refers to the ability to solve everyday problems or reason about applications. .. Creative reasoning refers to the invention of methods in thinking about problems. (p. 146)

Four interview participants' solving of optimization problems indicated that, within a paper-and-pencil environment, they depended on and were limited to analytical reasoning. However, they were able to exhibit analytical, practical, and creative reasoning with the help of the facilities that technology environments provided. This finding connects to our observation in Sect. 3.3 that dynamic environments or interactive technology might help PSMTs develop better understanding of content. Either practical and creative reasoning might help PSMTs develop deeper understanding or these forms of reasoning and development of deeper understanding depend on a common type of interaction with technology among successful PSMTs.

Six articles explored pedagogical ideas. They differ regarding whether they explore the use of video or the use of mathematics software, though all addressed some aspects of teacher questioning. Akkoc (2015) examined formative assessment skills within a computer-learning environment (e.g., GeoGebra, TI Nspire). Analysis of 35 PSMTs' pre- and post-workshop lesson plans and teaching notes indicated that participants improved their mathematical questioning regarding mathematical reasoning, assessment of prior knowledge, connections, and multiple representations, and they dramatically increased their use of questions assessing technical aspects of using technology. Davis (2015) investigated how 10 PSMTs read, evaluated, and adapted elements of a textbook lesson involving symbolic manipulation capabilities of computer algebra systems (CAS). A majority of the PSMTs adapted lessons to ask students to make predictions before using CAS and helping students understand the hidden procedures used by the technology but did not necessarily connect lesson elements to overarching lesson goals. These studies might suggest ways to improve teacher questioning yet underscore the challenge of coordinating questioning with other lesson aspects. They suggest how PSMTs might progress in some ways, regardless of their mathematical ability, but need additional support to apply knowledge in practice.

Arguably one of the most robust bodies of literature emerging around the use of technology in PSMT education regards the use of video in methods courses. However, researchers attend to different aspects of teaching episodes. For example, Santagata et al. (2007) examined how a video-based method course can develop PSMTs' ability in analyzing lessons guided by a three-step analysis framework that values goals and parts of the lesson, student learning, and teaching alternatives. Open-ended pre- and post-assessments from 140 participants revealed improved analysis. Taking a more targeted approach, Star and Strickland (2007) investigated how video use in a methods course could help develop PSMTs' noticing ability. Twenty-eight PSMTs' pre- and post-tests documented quantity and types of classroom events that teachers noticed before and after the course. After the pre-assessment, a multi-dimension framework (environment, management, tasks, content, and communication) was used to guide students' analyzing of videos throughout the course. The data analysis revealed that, although the PSMT generally lacked observational skills, they enhanced their skills in noticing important features of the classroom environment, mathematical content of a lesson, and teacher and student communication during a lesson. Moreover, Alsawaie and Alghazo (2010) conducted a quasi-experiment on the effect of using video lesson analysis on PSMTs' ability to analyze mathematics teaching. With 26 PSMTs participating in a quasi-experiment, the intervention seemingly remarkably improved participants' ability to analyze classroom teaching. These three studies support use of video and guided discussion to develop various PSMTs' noticing abilities.

In contrast to those interested in questioning and noticing, Rhine and colleagues (2015) investigated PSMT dispositions in a deliberately designed methods course that focused on developing ability to anticipate students' engagement with algebra using multiple integrated technological approaches (e.g., student thinking video database, class response system, and virtual manipulatives). Findings within a mixed methods design using a disposition survey indicated an impact on orientation toward student thinking and efforts to anticipate students' experience of the mathematics. The authors recognized the complexity of assessing disposition and a need for a longitudinal study to determine the effectiveness of using the combined technological resources. Evidence across the six studies shows the potential of using various technological tools and resources for developing PSMTs' mathematical reasoning, algebraic thinking, questioning skills, noticing ability, as well as challenges and complexities.

Acting as teachers in hypothetical situations in which students are using technology, PSMTs seem challenged in facilitating reasoning and problem solving. For example, Hähkiöniemi and Leppäaho (2011) examined how PSMTs guided students' reasoning in hypothetical situations where students were solving inquiry tasks with GeoGebra. Twenty PSMTs explored situations with GeoGebra then wrote their responses as teachers to the students' solutions. The authors concluded that participants had difficulties in guiding students to justify observations, in reacting to trial-and-error solution methods, and in elaborating on unexpected potentially productive ideas.

Eliciting thinking was also a challenge noted by Lee (2005), who examined how three PSMTs interpreted and developed in their role of facilitating students' problem solving with technologies (e.g., dynamic geometry, spreadsheets, probability simulators). A cycle of planning-experience-reflection was repeated twice to allow PSMTs to change strategies when they worked with two different groups of students. Case study methods revealed that the PSMTs desired to ask questions that would guide students in their solution strategies but recognized their own struggles in facilitating students' problem solving. In fact, the PSMTs assumed the role of an explainer for some portion of their work with students. However, they used technological representations to promote students' mathematical thinking or focus their attention.

Seemingly fundamental to facilitation of student reasoning and problem solving is anticipating and eliciting student thinking. Lee and Hollebrands (2008) developed mathematics methods course materials and situations based on enhanced capabilities of the technology to prepare teachers to teach data analysis and probability topics. They developed video cases focusing on enhancing PSMTs' knowledge of students' thinking as they were learning about data analysis within technology-enhanced environments. The 15 participants in pilot tests of the materials seemingly improved in their understanding of statistical and probabilistic concepts and their use of technological tools but not in their pedagogical understandings. Findings resulting from Wilson et al. (2011) extensive analysis of sixteen PSMTs' work on the video-case and student work with technology indicated that reflection on the video case materials provide opportunities for PSMTs' building models of students' thinking.

The studies cited in this section provide evidence that redesigning methods courses to have PSMTs working with dynamic mathematics environments might be productive but PSMTs' struggles to facilitate students' reasoning and problem solving are nontrivial. Reflection with video cases could enhance PSMTs' understanding and anticipation of student thinking, which seems essential in using technology to support students' reasoning and problem solving. Haciomeroglu et al. (2010) shared similarly positive findings about effective lesson development and positive influence on perspectives about teaching and learning of mathematics with technology given use of GeoGebra in a methods course. However, as Haciomeroglu et al. (2010) note, PSMTs' lack of teaching experience remains an issue.

Insight into the connection between preparatory courses and classroom teaching performance might come from Meagher et al. (2011). They examined PSMTs' evolving attitudes regarding the use of various digital technologies (TI-Nspire) in the context of the interplay between their field placements and their use of technologies in inquiry-based lessons. Their 22 PSMTs enrolled in a mathematics teaching methods course that included two field experiences. Several products arose from their analysis of data: a mathematics technology attitude survey; three short surveys regarding philosophy of teaching; experiences with technology in the class; the interactions among the class, mathematics content, technology, and field placement; an open-ended exit survey; and five lesson plans. First, if PSMTs are to develop a positive attitude toward technology use in their instructional practice, more than a methods class is required. In particular, modeling of exemplary practice in the field placement has a crucial, perhaps decisive, effect on their attitudes. Second, the most significant improvement in the quality of the PSMTs' lesson plans regarding inquiry-based teaching with technology came when they had field placements in technology-rich environments.

5 Teacher Practicum and Technologies

Two articles examined PSMTs using technology during student teaching, which is arguably the richest field experience in a PSMT's preparation. A contrast of the two articles is informative.

Fraser et al. (2011) investigated effects of use of technology (e.g., Sketchpad, SMART board) by 16 PSMTs in a technology-rich, five-year teacher education program on lesson planning and quality of classroom life. Pre- and post-placement interviews and five 90-min teaching episodes with debriefings, weekly reflective journals, and lesson artifacts evidenced PSMTs' views of planning, effective mathematics teaching, potential benefits of technology, and motives for using technology. One of the findings was that PMSTs refocused their teaching when they were diverted from their plans.

In methodological contrast to Fraser and colleagues, Clarke (2009) presented a case study of how a PSMT experienced and perceived technology use during student teaching practice. The teacher had expertise in using technologies (TI-83 plus) and was interested in implementing a learner-centered approach through integrating technology. He did not achieve this goal. The author raised a broad concern about provision of necessary resources, support, and professional development.

6 What Do We Know and What Do We Need to Know

The preceding literature review suggests three positive conclusions. First, four studies suggests that engagement with interactive, dynamic tools could enhance PSMTs' understanding of subject knowledge and develop their positive attitudes toward using technologies in their further teaching. Much remains unknown about how to develop and implement materials and initiatives to help PSMTs develop and employ knowledge. For example, although positive outcomes in using video cases in methods courses are documented, specifics of how to develop and use high-quality video cases need to be further explored (Borko et al. 2014).

Second, incorporation of mathematics technology and practice-based video cases in teaching methods courses could help PSMTs in questioning and lesson planning and in anticipating, noticing, and eliciting student thinking. Incorporating technologies in mathematics and methods courses and connecting courses with field experiences could promote PSMTs' awareness of implementing student-centered mathematics instruction and help them identify as technology innovators.

Third, perhaps PSMTs' progress in facilitating student thinking, reasoning, and problem solving seemed elusive. It also could be a sign for long-term studies of development. The ability to notice and elicit student thinking might need to be minially established before teachers can be expected to succeed in eliciting and examining and facilitate student reasoning and problem solving.

Preparing PSMTs to teach secondary mathematics with technology is an important endeavor and an emerging research area in need of systematic studies and a global effort to develop a cohesive body of literature.